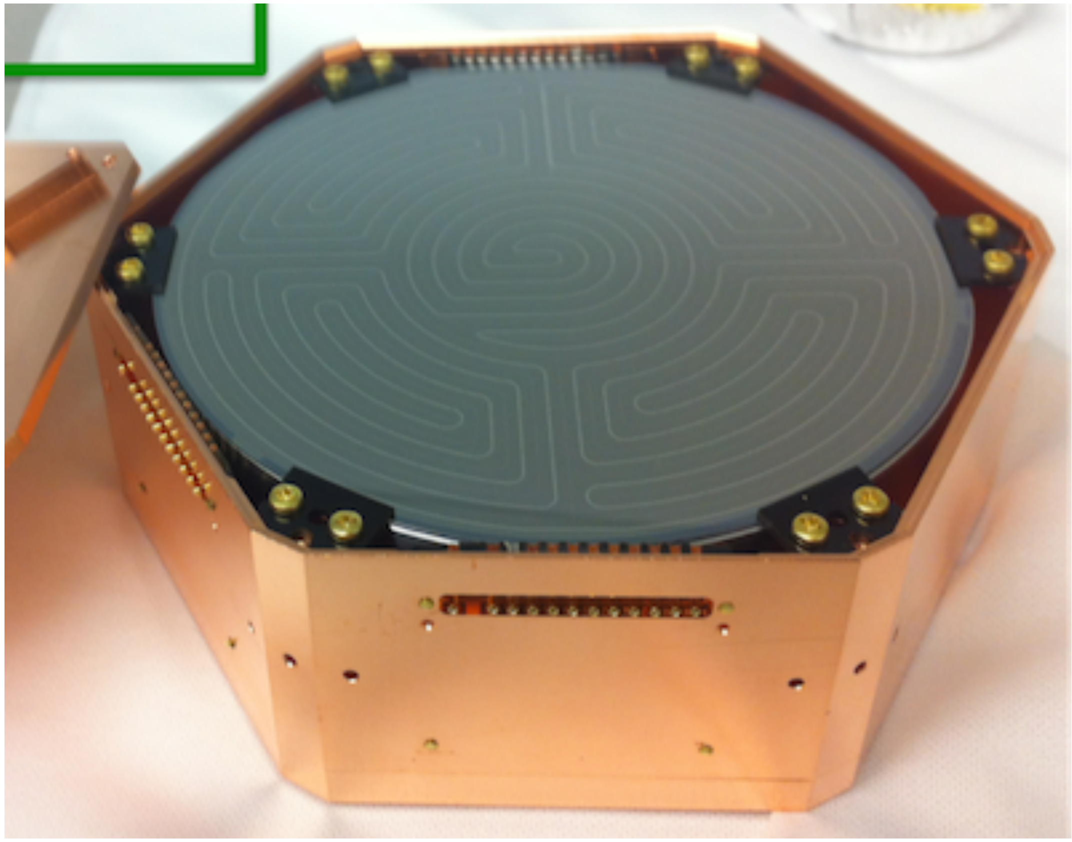


Detector Technology of Super CDMS

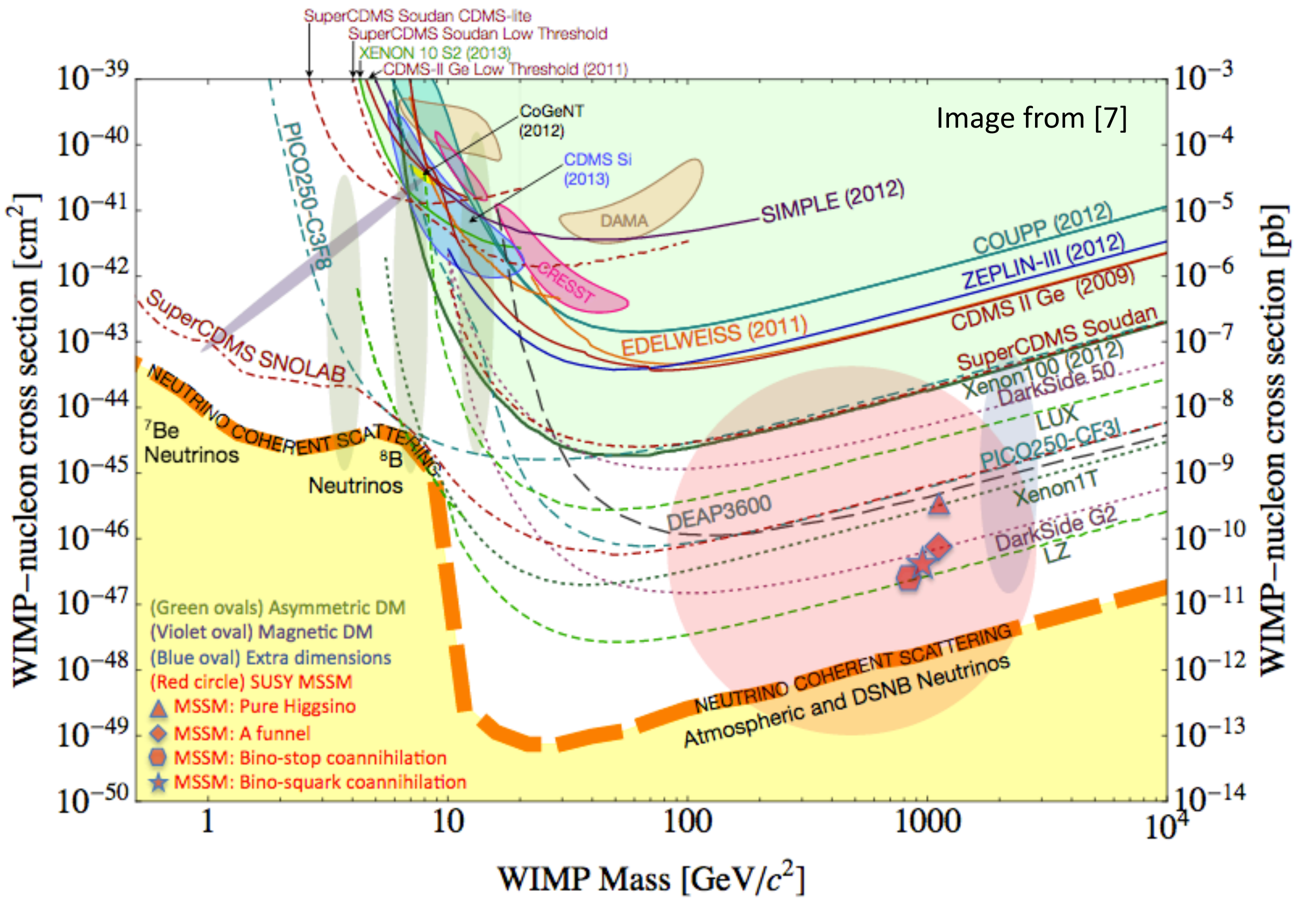
Caleb Fink

Physics 290E Fall 2016

Outline

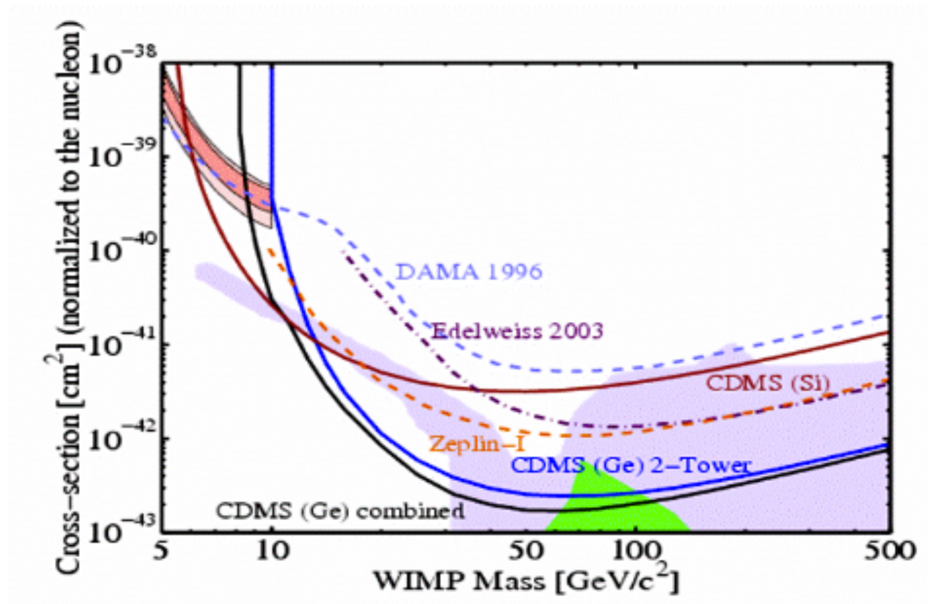
- History of CDMS collaboration
- Overview of SuperCDMS
- SuperCDMS SNOLAB detectors

Search for Dark matter



History

- CDMS: Cryogenic Dark Matter Search
- CDMS I
  - 1998 to 2002
  - Located at Stanford Underground Facility
  - 6 detectors, 1kg Ge detector mass



CDMS II

- 2003-2009
- Located at Soudan Underground Laboratory in Minnesota
- 30 detectors, ~6kg Ge detector mass
- Set the most sensitive limits on DM at the time

SuperCDMS Soudan

- 2009-2014
- Soudan underground laboratory
- 15 detectors, 9kg Ge detector mass

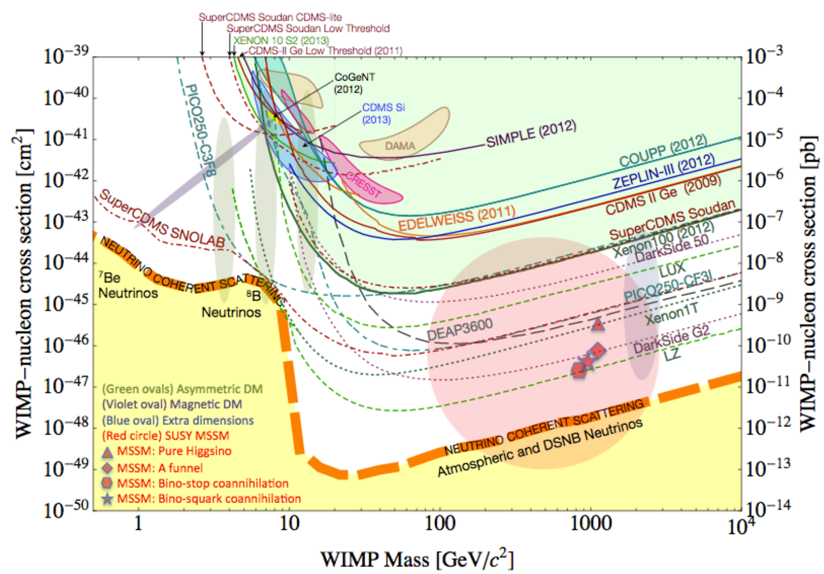
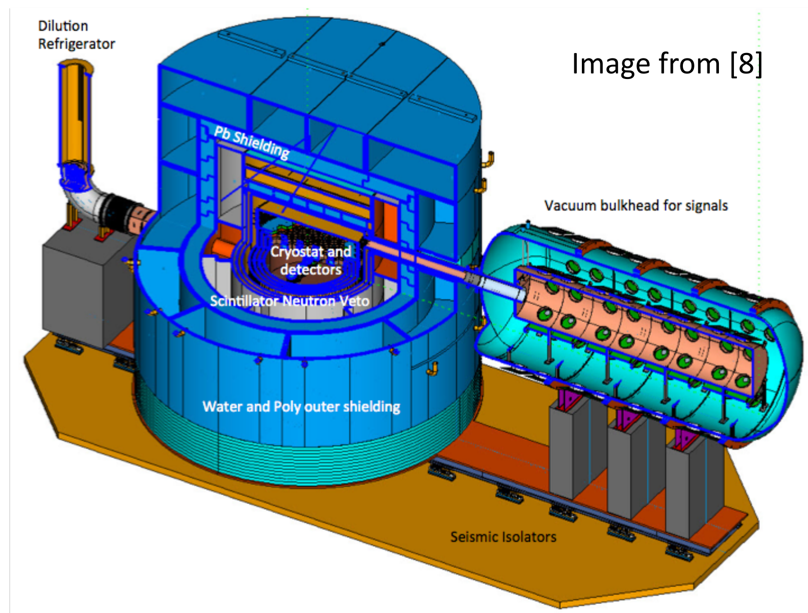


Image from [7]

Super CDMS SNOLAB

- Currently in R&D phase
- Plan to begin operation in 2020
- Located 2km underground at SNOLAB in Sudbury, Canada



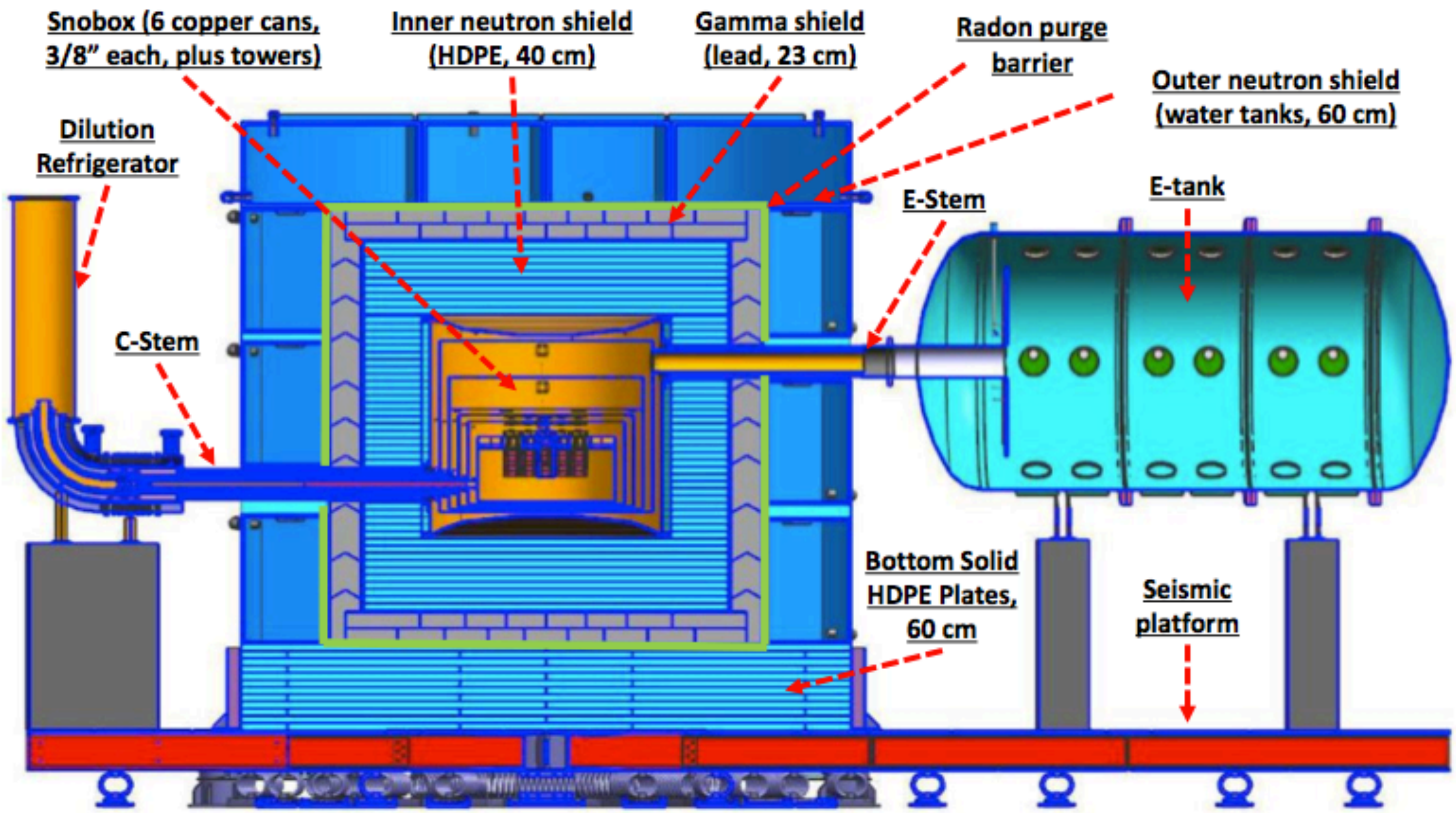

Snobox (6 copper cans, 3/8" each, plus towers)
Inner neutron shield (HDPE, 40 cm)
Gamma shield (lead, 23 cm)
Radon purge barrier
Outer neutron shield (water tanks, 60 cm)
Dilution Refrigerator
E-Stem
E-tank
C-Stem
Bottom Solid HDPE Plates, 60 cm
Seismic platform

Image from [6]

Detector Tower

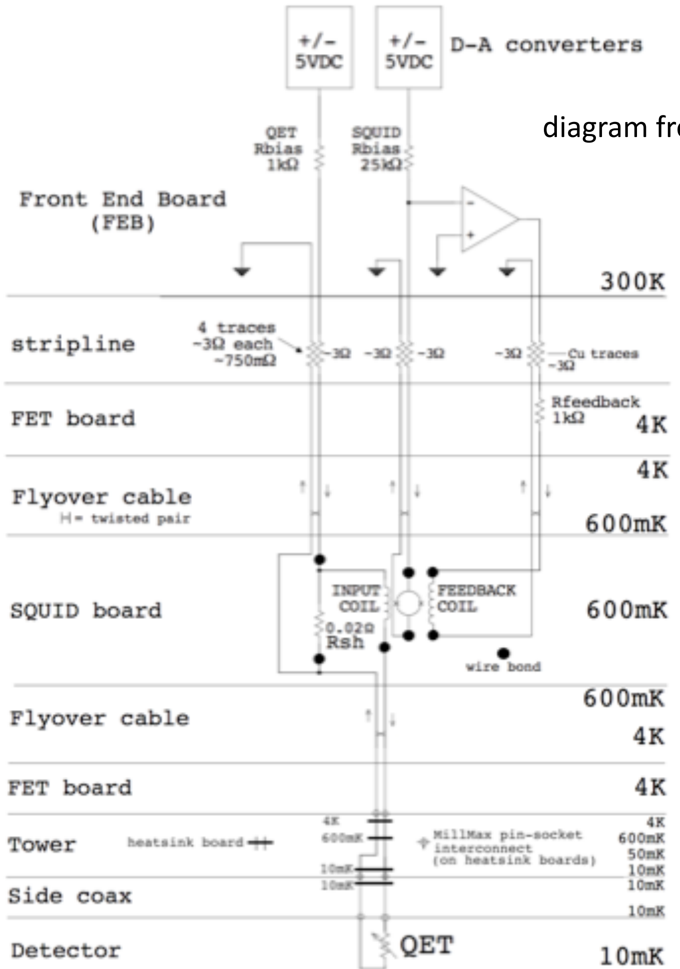


diagram from [4]

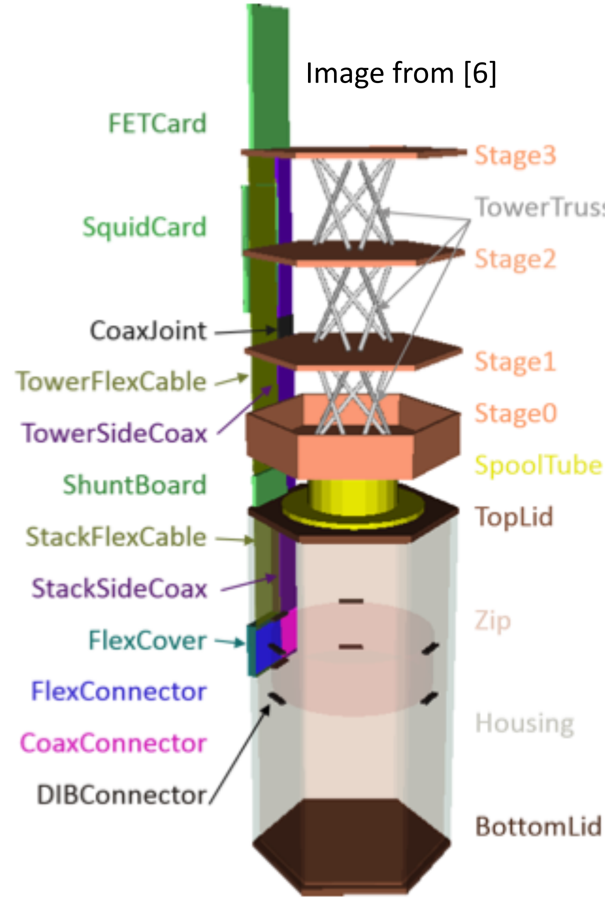
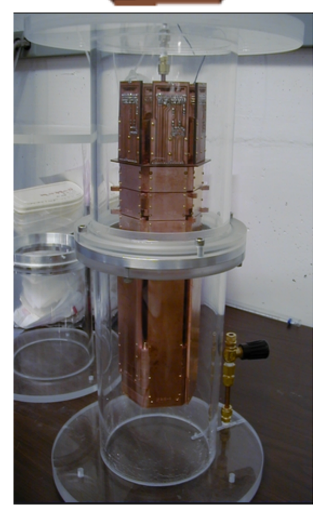


Image from [6]



Why cryogenic temperatures?

- Two reasons
  - Thermal noise
  - Energy resolution
- Thermal noise goes like

$$\sigma \propto \sqrt{T}$$

- Energy resolution is thus

$$\Delta E = \sqrt{k_B T^2 C}$$

- Detectors are operated at ~15-30mK
- For materials that obey Debye's law,

$$C \propto MT^3$$

- Which makes energy resolution:

$$\Delta E \propto \sqrt{MT^5}$$

Detectors

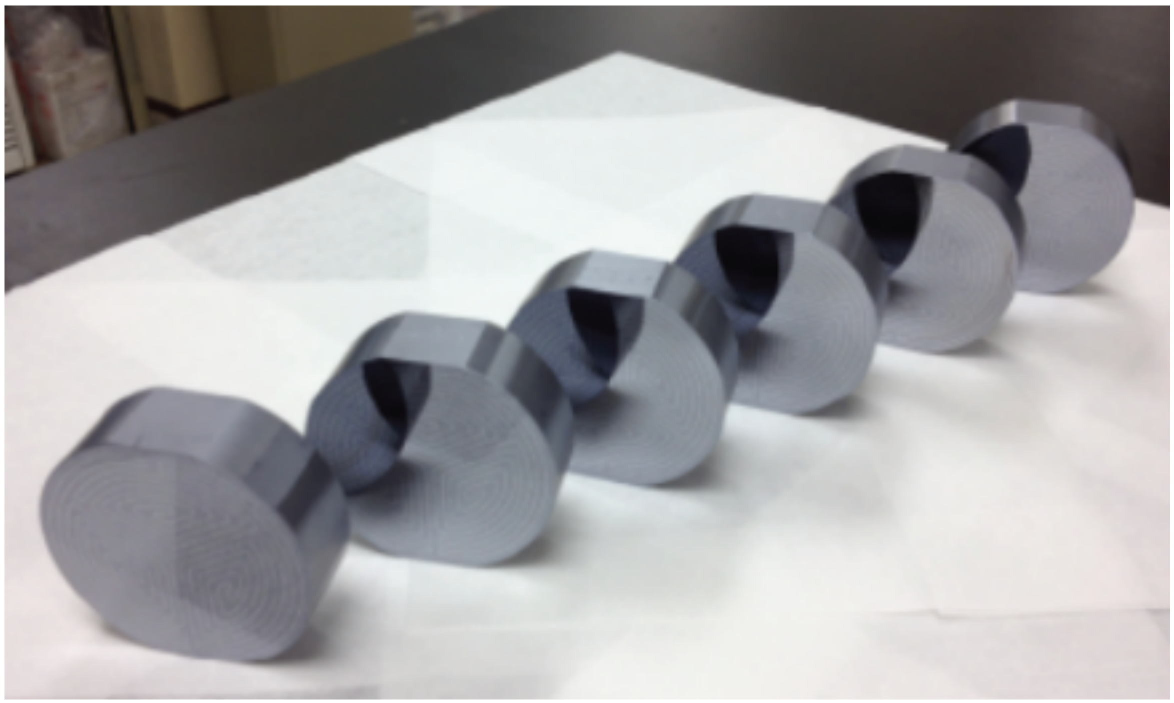


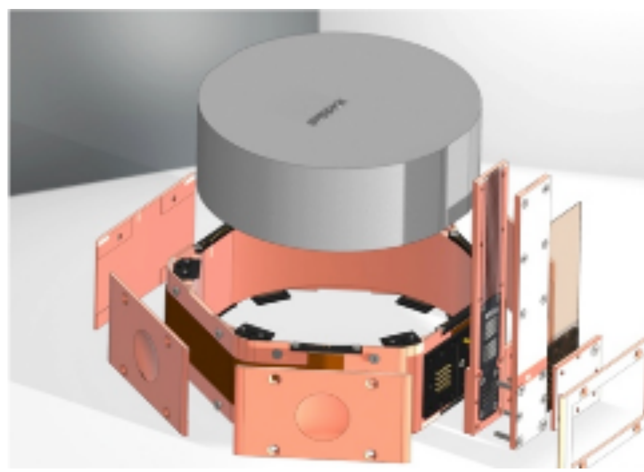
Image from [9]

- Two types of detectors, iZIP and HV

	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure (kg·yr)	56	4.8	44	9.6
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

Table from [6]

Image from [9]



iZIP

- interleaved Z-dependent Ionization and Phonon
- Sensors mounted on top and bottom of either Ge or Si crystal
- Optimized for both Ionization and Phonon collection
- Most sensitive to >5GeV mass DM

Image from [5]

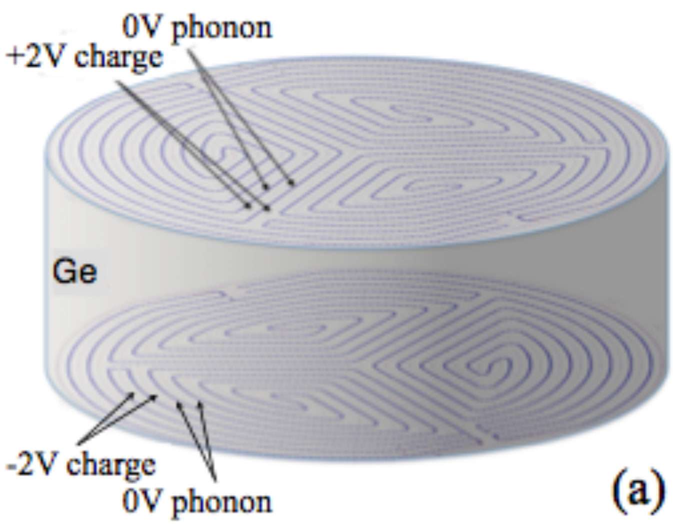
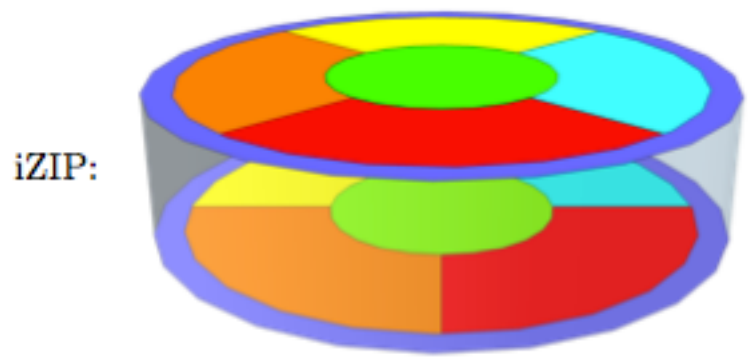


Image from [6]



Electron Recoil rejection

- Phonon production for NR and ER events are nearly identical
- NR events are much less efficient at producing charge carriers
- Typically ~1/3 the ionization of equivalent ER

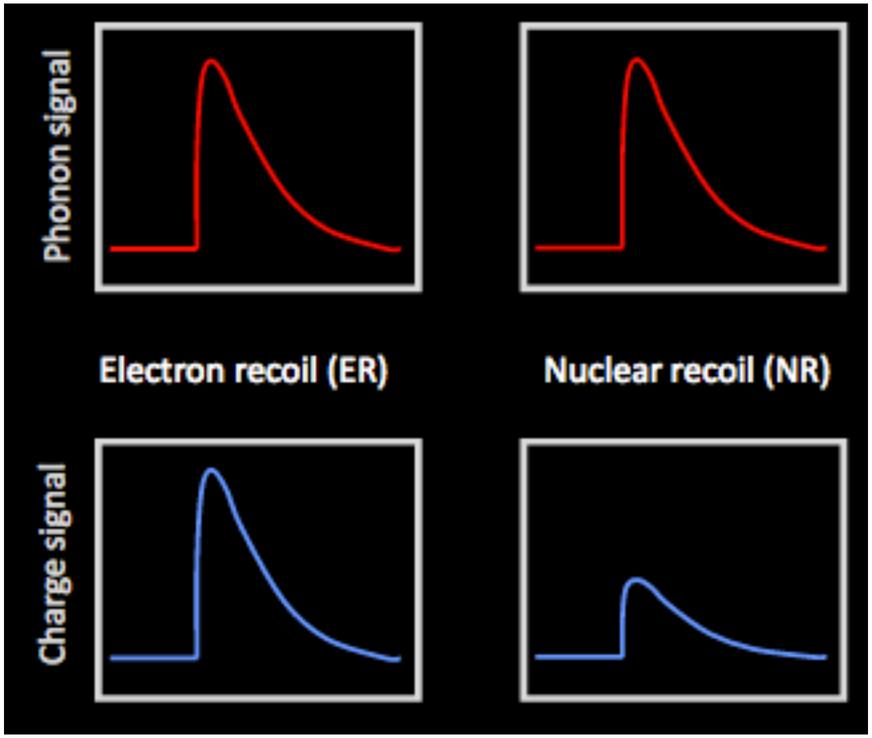
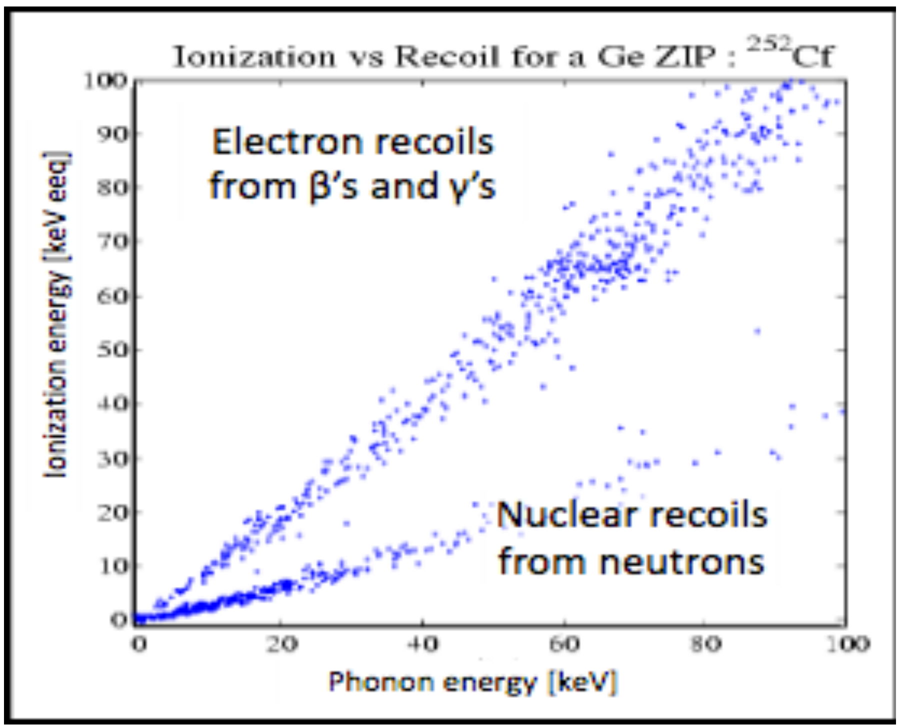
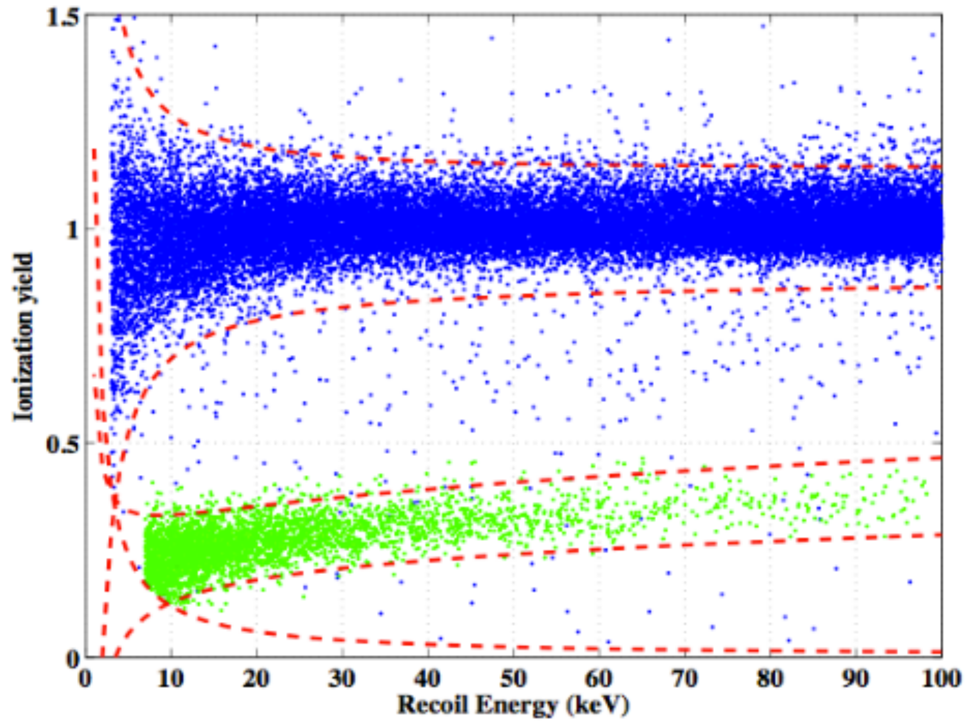


Image from [8]

Electron Recoil rejection

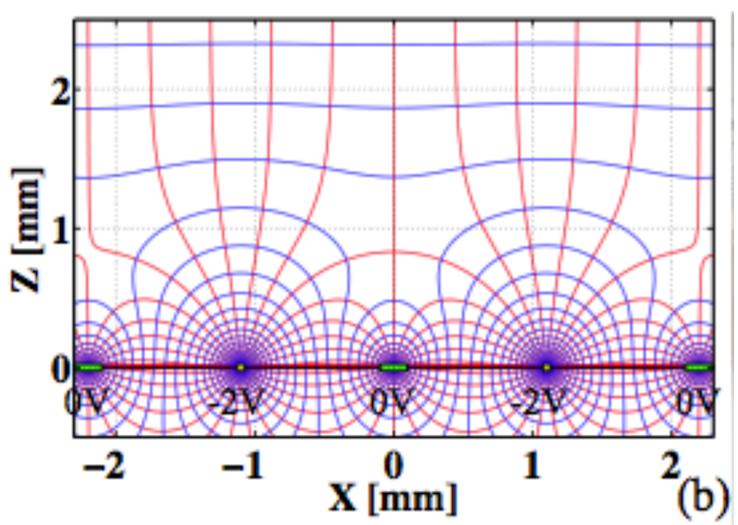


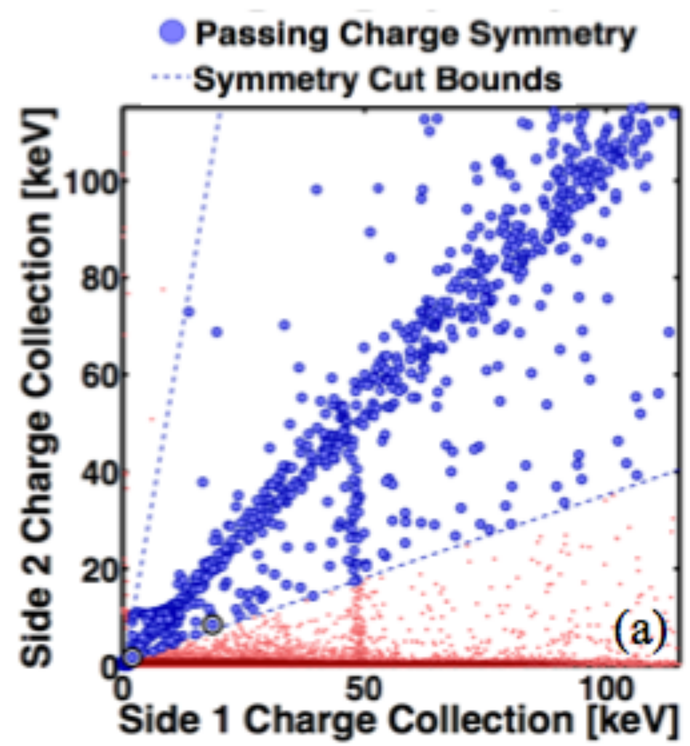


Images from [7]

Surface Rejection

- 5-10V bias on ionization channels, phonon channels are grounded





Images from [5]

Electron Recoil rejection

- After Symmetry cut is made

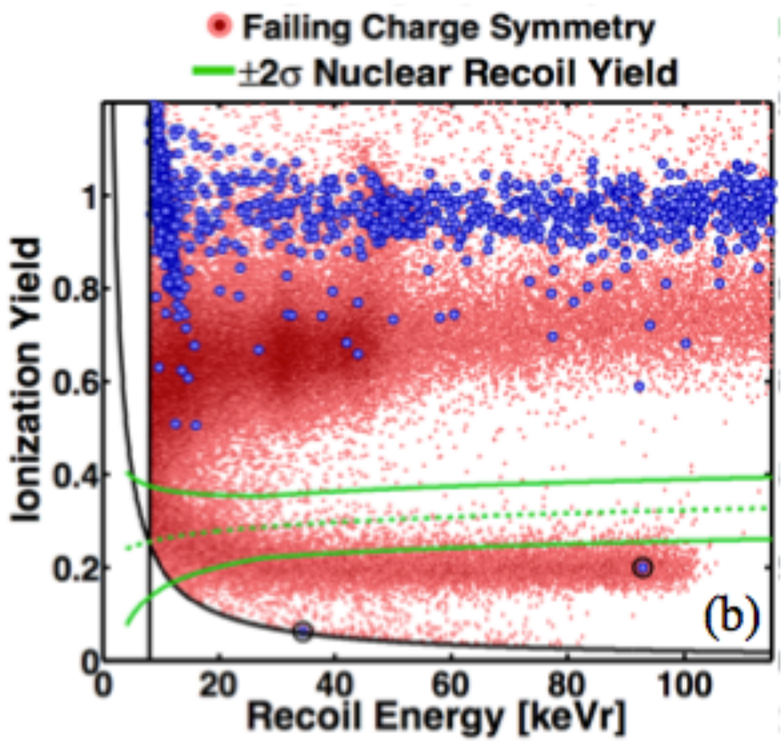


Image from [5]

Charge Amplification

- Charge amplification is handled by BJT based feedback amp with High-Impedance JFET preamp front end
- JFET located at 4K stage, but must be heated to ~150K to operate
- Main amplification is done at room temp, then fed back to 4K stage

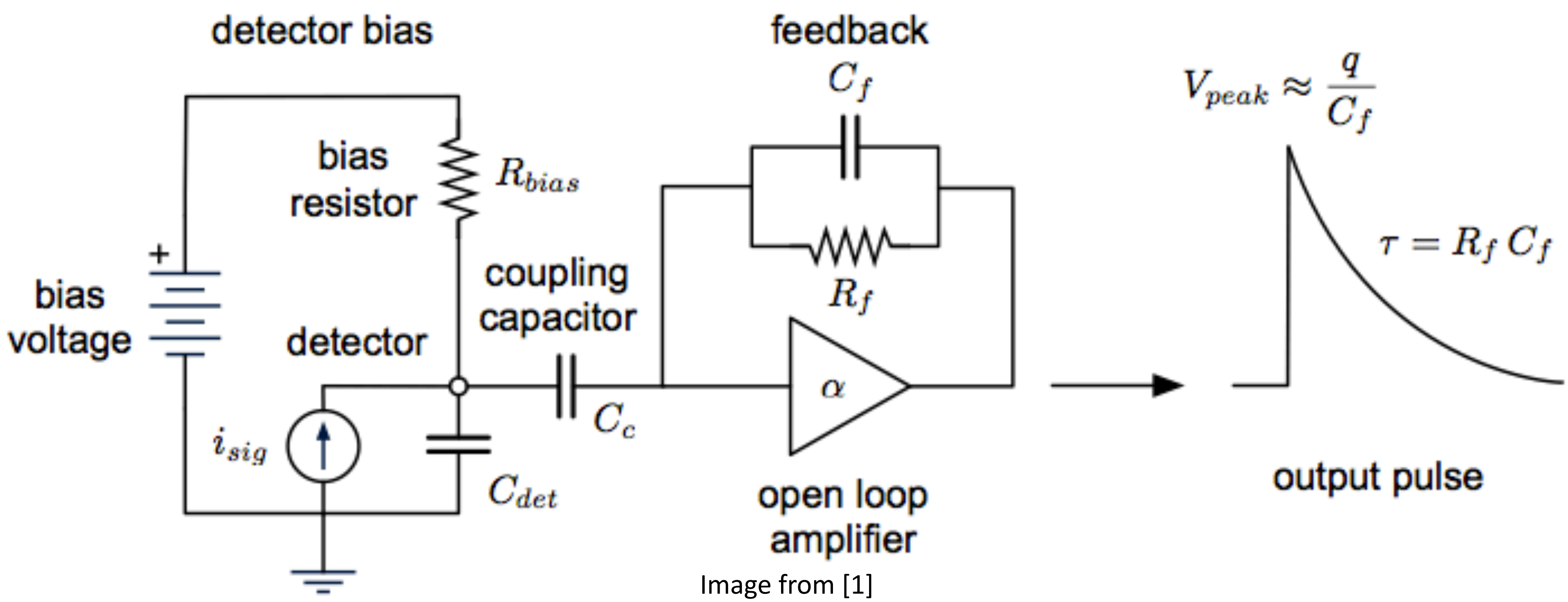


Image from [1]

- Integrated charge in proportional to number of electron hole pairs produced in event
- In Ge it takes ~3eV of recoil energy to produce electron-hole pair, the charge can be converted to energy
- The energy resolution of the amp is determined by

$$\sigma_E = \frac{3 \cdot \sigma_{\hat{A}}}{e} = \frac{3}{e}\left(4\int_{f_{min}}^{f_{max}} \frac{|\gamma|^2}{e^2_{n,total}} df\right)^{-1/2} \quad \text{(in eVee)},$$

- In SuperCDMS Soudan, typical resolution is about 460eVee, where as new amps tested at Berkeley have been shown to be about 250eVee

HEMT Amplification

- High Electron Mobility Transistors
- Operate at cryogenic temperatures
- Dissipate about 100 microWatts vs typical JFET with 5mW
- Significantly lower noise than JFET

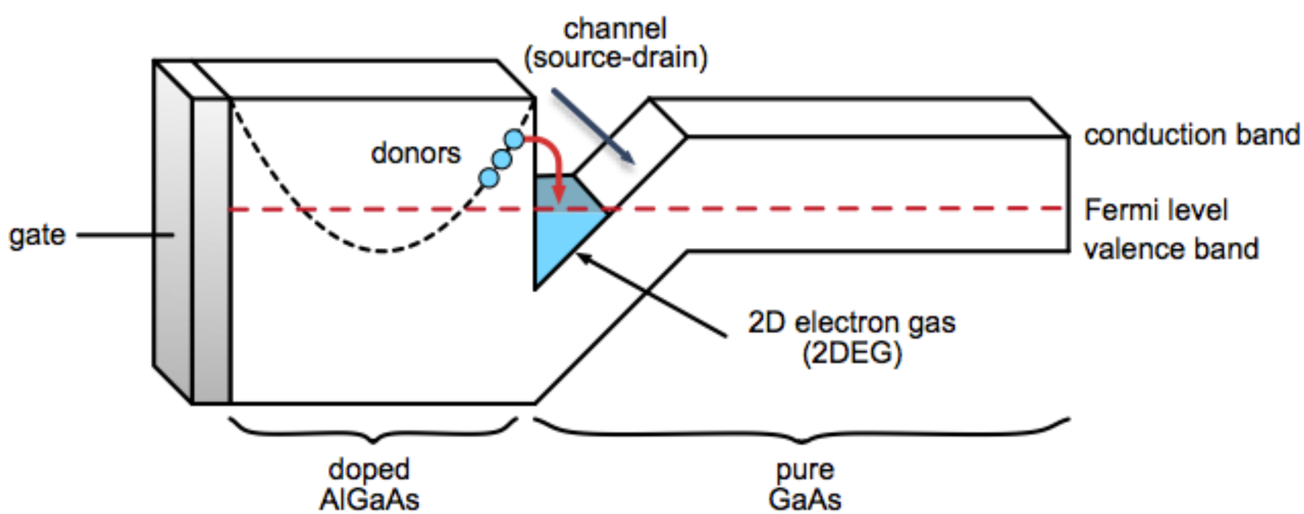


Image from [1]

- Two designs were tested
  - Modifying the original JFET amplifier by replacing the front end with HEMT
  - Completely cryogenic HEMT based amplifier

- Modified FET amp was shown to match performance of original amp, but with lower power usage
- Completely cryogenic HEMT amp has significant increase in noise performance

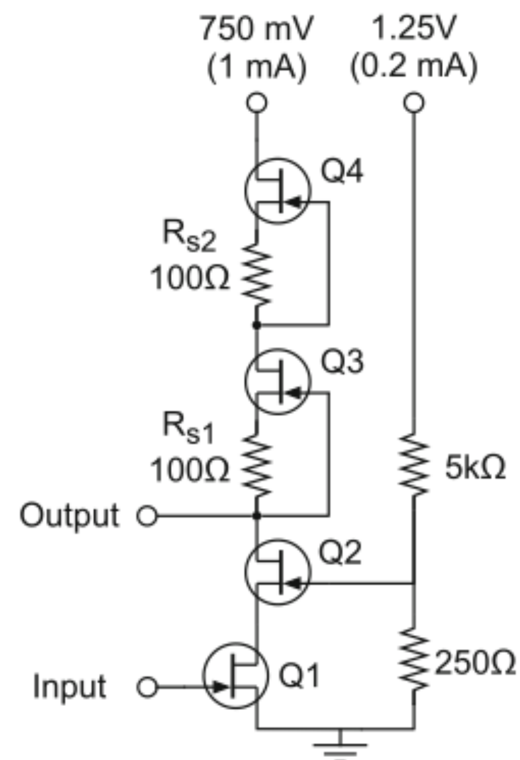
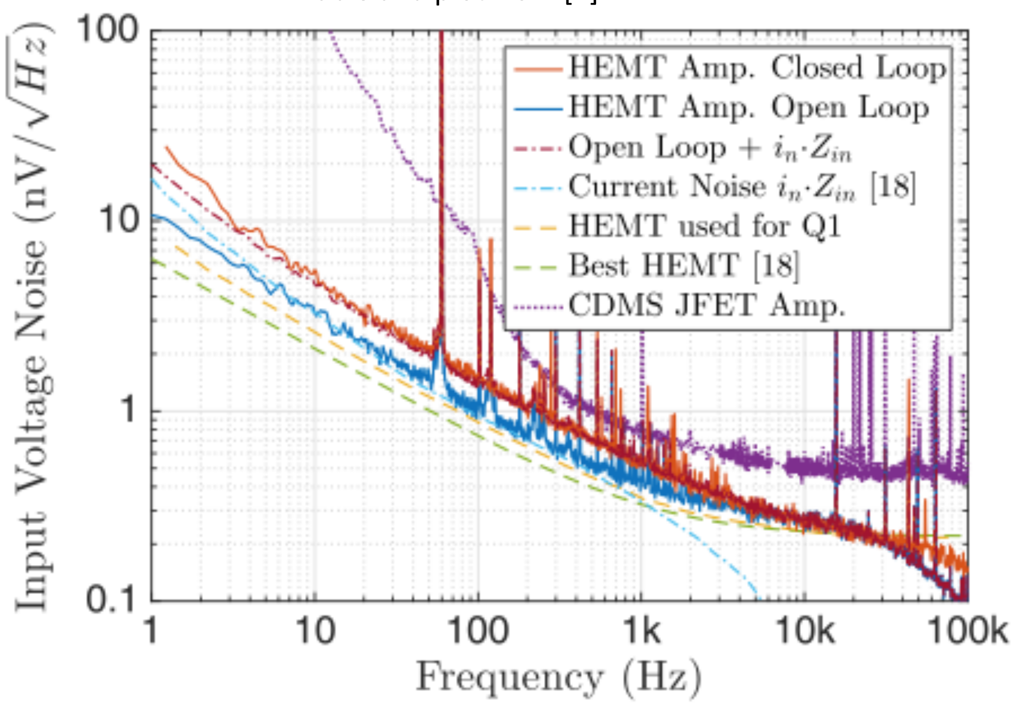


Image from [2]

Leakage current	Charge resolution (eV)		
(10^{-15} A)	HEMT Amp.	CHEMT Amp. (best HEMT)	CDMS JFET Amp.
≤4	106	87	228
10	110	92	229
100	126	110	231

Table and plot from [2]



How to detect phonons?

- In scattering event, interaction results in production of charge carriers (electron-hole pairs) and athermal phonons
- If detected before they thermalize, they can provide spatial reconstruction
- Athermal phonons are detected via QETs (Quasiparticle-trap-assisted Electrothermal-feedback Transition edge sensors)

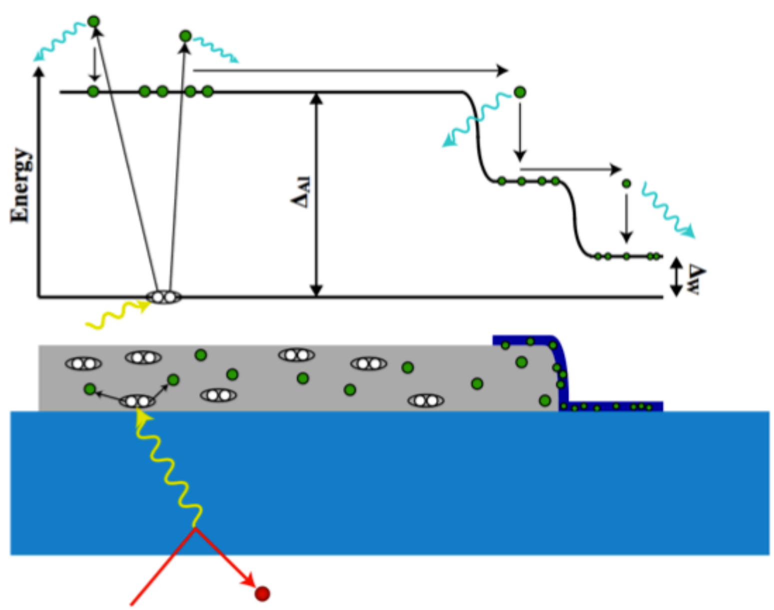
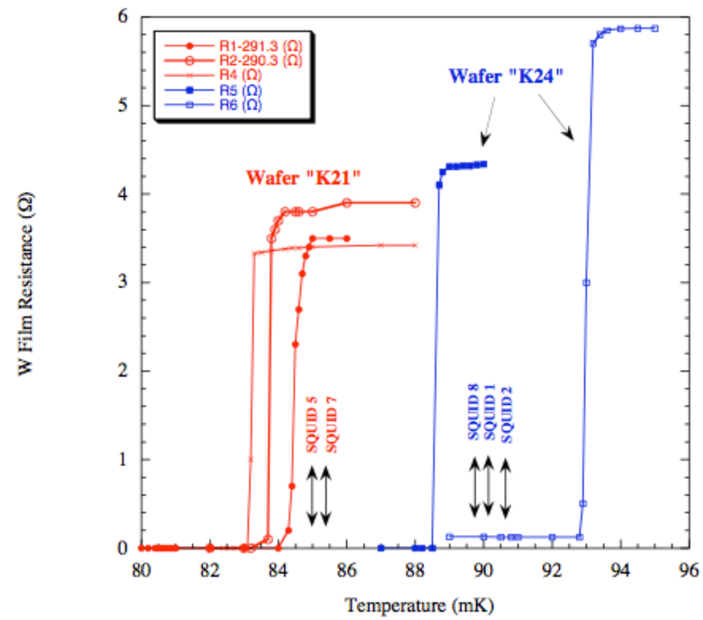


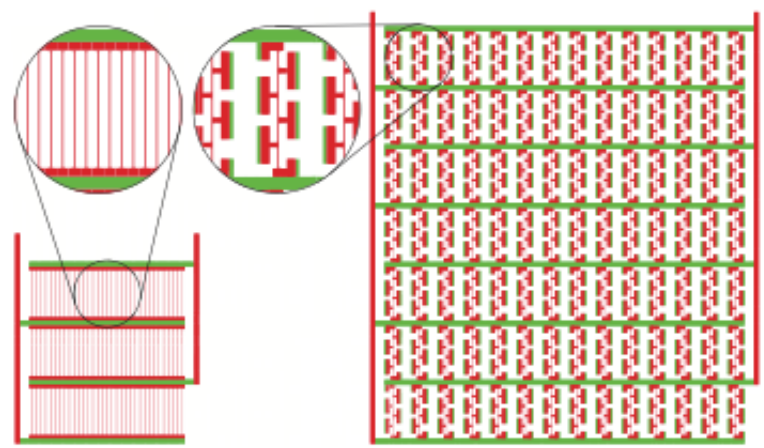
Image from [1]

TES

- Superconducting film biased at transition between normal and superconducting
- Must be voltage biased to stay in transition region
  - Increase in temperature increases resistance
  - Increase in resistance decreases the Joule heating (V^2/R)
  - Decrease in Joule heating leads to decrease in temperature



Images from [4]



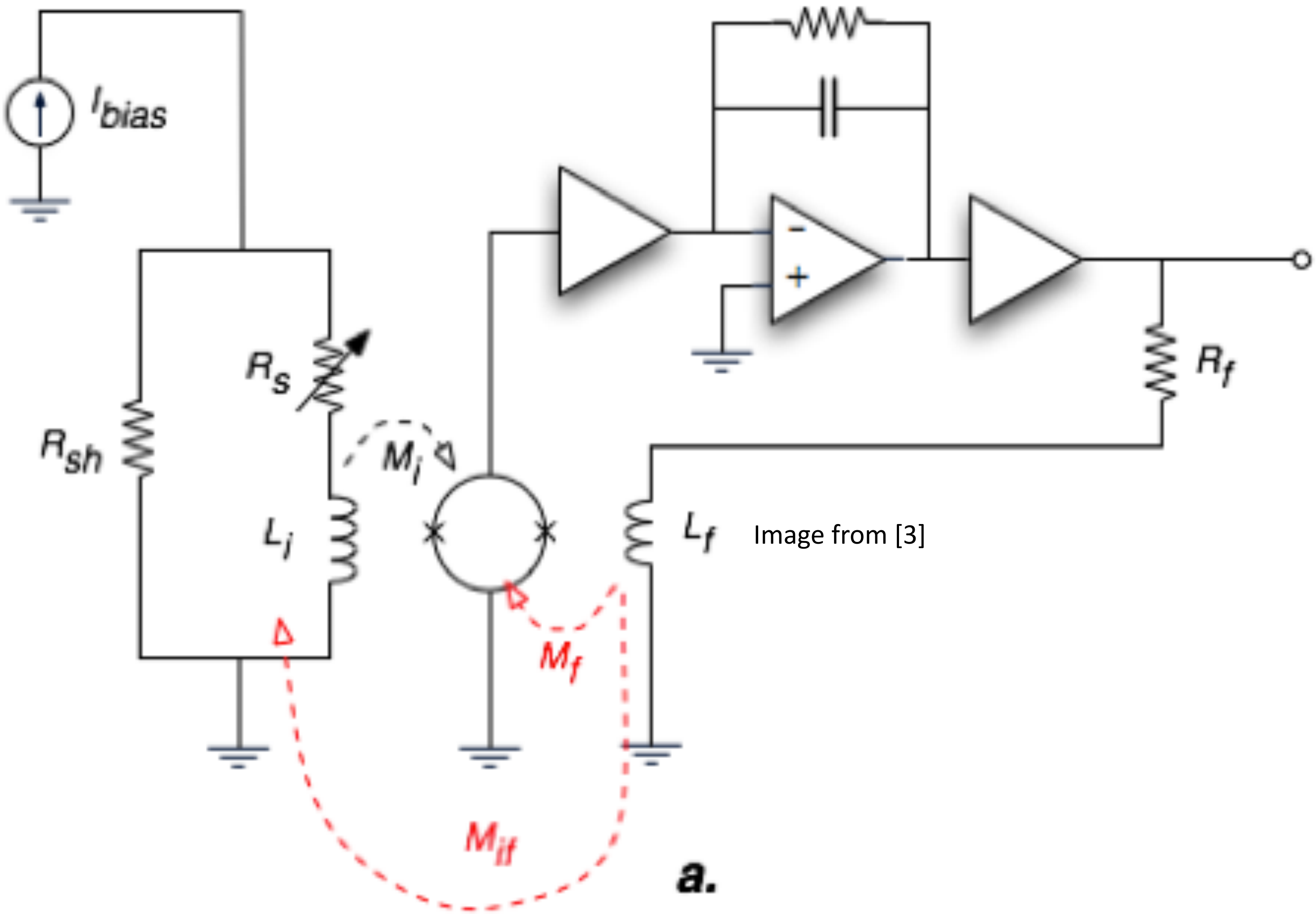


Image from [3]

Luke-Neganov Phonons

- When charge carriers are drifted across the crystal, the carriers themselves produce phonons
- Luke phonons can obscure the measurement of the primary phonons

$$E_{phonon} = E_{recoil}\left(1 + \frac{q\Delta V}{\epsilon}\right)$$

HV detector

- "High Voltage"
- Dual layer single channel detector
- Same material and overall shape as iZIP, but layout is optimized for phonon collection
- Most sensitive to 1-5GeV mass DM
- Takes advantage of Luke-Neganov phonons

HV:

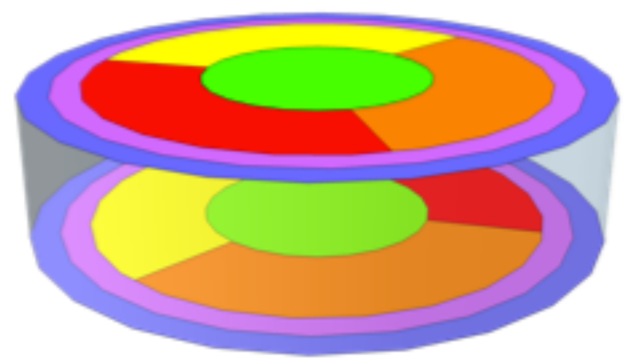


Image from [6]

Luke-Neganov Amplification

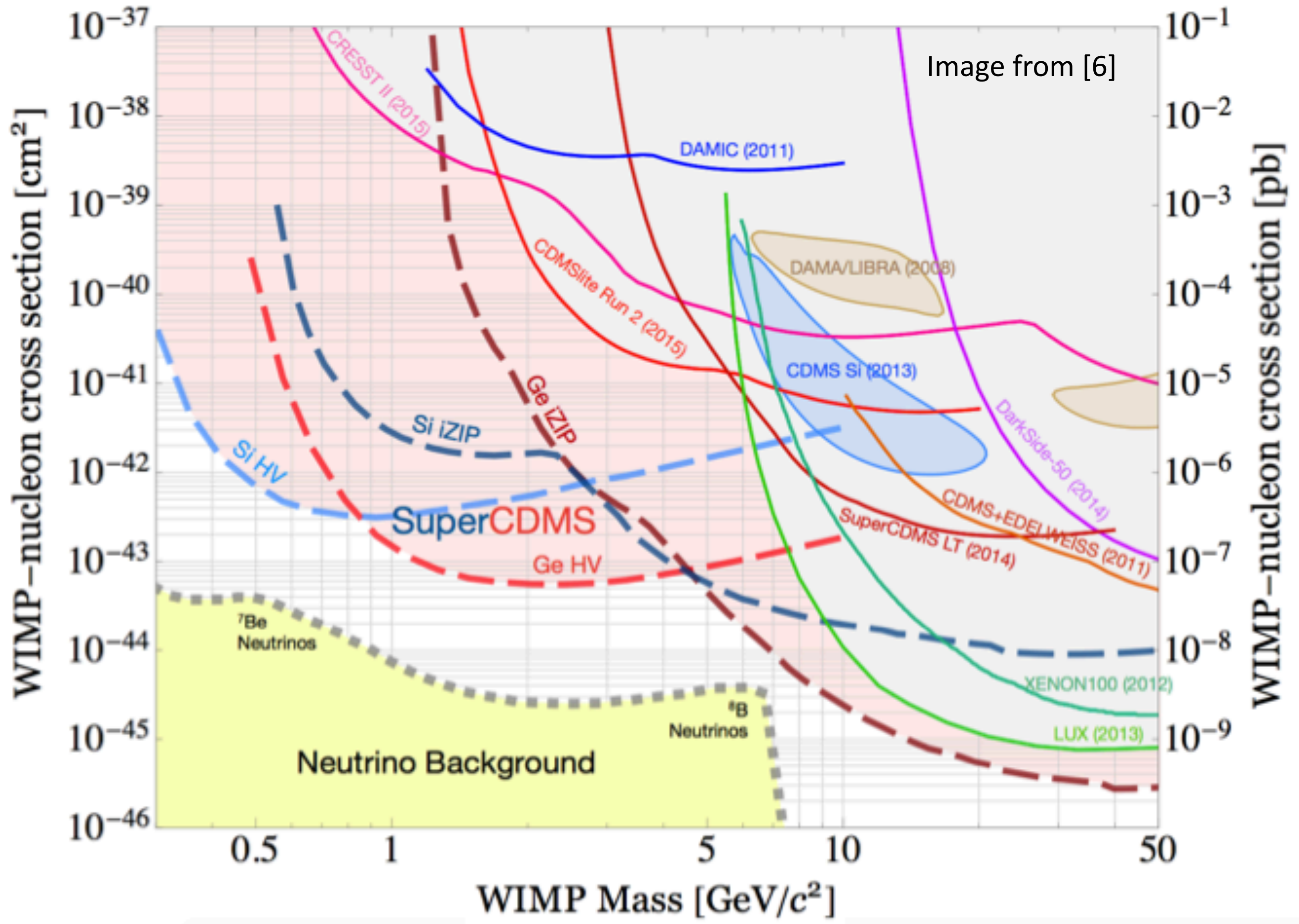
- Measure ionization via phonons rather than charge
- Drift electron hole pairs across negative bias, measure heat dissipated during process
- By increasing the bais resistance, the number of Luke phonons created increases, yet the electronic noise of the phonon readout electronics remains unchanged
- This comes at the cost of event-by-event background reduction

- For large enough bias voltage, Energy resolution will go like

$$\Delta E \approx \frac{eV_b}{\epsilon}$$

- Thus, for a bias of about 100 volts, this should allow for detection of single electron hole pair

Proposed limits



Sources

- [1] A. Phipps, *Ionization Collection in Detectors of the Cryogenic Dark Matter Search.* PhD thesis, University of California Berkeley, 2016
- [2] A.Phipps, *et al.* An HEMT-Based Cryogenic Charge Amplifier for Sub-Kelvin Semiconductor Radiation Detectors. J. Low Temp Phys, 10909-016-1475-2, 2016
- [3] K. Sundqvist, *Carrier Transport and Related Effects in Detectors of the Cryogenic Dark Matter Search*
- [4] M. Pyle, *Optimizing the Design and Analysis of Cryogenic Semiconductor Dark Matter Detectors for Maximum Sensitivity.* PhD thesis, Stanford University, 2012
- [5] R. Agnese *et al.* Demonstration of Surface Electron Rejection with Interleaved Germanium Detectors for Dark Matter Searches. arXiv:1305.2405v3, 2013

- [6] R. Agnese *et al.* Projected Sensitivity of the SuperCDMS SNOLAB experiment. arXiv:1610.00006v1, 2016
- [7] D. Bauer, *et al.* Snowmass CF1 Summary: WIMP Dark Matter Direct Detection. arXiv:1310.8327v2, 2013
- [8] W. Rau. SuperCDMS at SNOLAB. Presentation 2016
- [9] J. Hall. CDMS low ionization threshold experiment. Presentation 2013